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DEC 77 J G PREIS, T MALICKA F19628-78-C-0006
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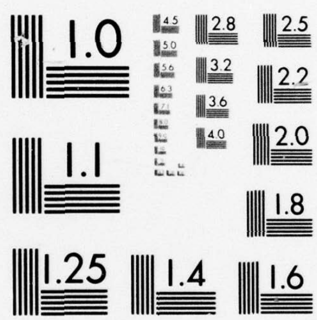

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AN EMC ANALYSIS OF THE PROPOSED ASDE-3 AIRPORT SURFACE DETECTION EQUIPMENT RADAR

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20590

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16. Abstract

This report addresses the electromagnetic compatibility (EMC) between Airport Surface Detection Equipment (ASDE-3) radars to be located at major U.S. commercial airports and the communications-electronics equipments near proposed ASDE-3 sites. Three types of the environmental equipments are considered: ground-based equipments, aircraft landing systems, and airborne equipments.

Predicted interfering signal levels are compared against established receiver interference thresholds to determine interference problems, and frequency management techniques are identified as potential solutions to the problems. It is determined that the recommended solutions are applicable regardless of whether ASDE-3 operates in the single-frequency or the frequency-agile mode.

A follow-on study is recommended to determine the extent of ASDE-3 radar interference to certain classes of military airborne radars operating in the same frequency band.

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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METRIC CONVERSION FACTORS

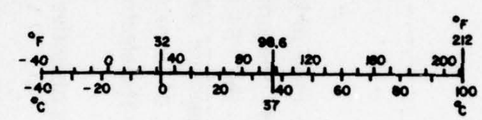
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) is developing a new Airport Surface Detection Equipment (ASDE) radar referred to as ASDE-3. The ASDE-3 presentation will provide ground traffic control personnel with a means of identifying and controlling vehicular traffic on airport surfaces during all weather conditions in which the airport is operational.

The ASDE-3 will utilize the 15.7-17.7 GHz frequency band; operation in the 15.7-16.2 GHz band, on a co-equal basis with military equipment, has been provided for by the Office of Telecommunications Policy (OTP) under provisions of the National Table of Frequency Allocations.

FAA has requested that the DoD Electromagnetic Compatibility Analysis Center (ECAC) determine what, if any, EMC problems will exist when ASDE-3 is deployed at 33 planned sites in the United States.

Environmental communications and electronics (C&E) equipments operating in or adjacent to the 15.7-17.7 GHz frequency band and located within 100 miles (ground-based) or line-of-sight (airborne) of the ASDE-3 sites were identified and then analyzed for potential EMC impact to and from the ASDE-3 radar.

Predicted interfering signal levels were compared against established receiver interference thresholds to determine interference problems. Wherever possible, frequency management techniques were identified as potential solutions to the problems.

EXECUTIVE SUMMARY (Continued)

The analysis results are:

1. ASDE-3 can operate compatibly in the 15.7-17.7 GHz band at all proposed ASDE-3 locations, except that certain military ground-based radars located in the vicinity of the Miami, Las Vegas, Portland, OR, and Honolulu airports, and the airborne landing receivers used at airfields in the vicinity of Los Angeles and Atlanta airports may receive interference from ASDE-3. To ensure compatibility with ASDE-3, frequency separation and/or time sharing techniques will be required at these locations.

2. Certain classes of military tactical airborne radars operating at selected military training areas in the US may receive interference from or cause interference to ASDE-3 radars deployed at airports in the same region. Further analysis of the interactions between ASDE-3 and these equipments is required to determine the extent of the degradation.

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SECTION 1

INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA) is planning the development of a new Airport Surface Detection Equipment (ASDE) radar referred to as ASDE-3, for use at major airports within the US. ASDE-3 will provide the control-tower personnel with a clear and accurate presentation of airport runways, taxiways, and aprons and any stationary or moving aircraft or vehicles on these surfaces during all weather conditions in which the airport is operational. Design specifications for the ASDE-3 call for an effective range of three nautical miles under heavy rain conditions (16 mm/hr), and a capability of providing a presentation adequate to allow the control-tower operator to distinguish between surface vehicles, light aircraft, and heavy commercial aircraft.

A Request For Proposal and ASDE-3 specification[1] was prepared by the Transportation System Center (Department of Transportation) in February, 1976; proposals were subsequently received from contractors. It is anticipated that an ASDE-3 can be procured and installed at an airport for testing by the late 1970's.

The Spectrum Management Staff of the FAA has requested the Electromagnetic Compatibility Analysis Center (ECAC) to perform an EMC analysis for ASDE-3 operating in the 15.7-17.7 GHz frequency band. The first portion of this project was completed

[1] *Request for Proposal No. TSC/632-0174-GMF*, Department of Transportation, Transportation Systems Center, Cambridge, MA, February 23, 1976.

in May 1976; it provided comments on the EMC requirements in the ASDE-3 specification, and identified categories of equipments in the communications and electronics (C&E) environment for which EMC must be considered once the ASDE-3 design parameters are established. The second portion of the project is described in this report.

OBJECTIVE

The objective of this analysis was to identify potential EMC problems that may result from the introduction of ASDE-3 radars into the environment and to recommend possible solutions to the EMC problems identified.

APPROACH

Characteristics of various contemplated ASDE-3 radars were investigated, and typical transmitter spectrums and receiver thresholds were determined. The environmental equipments considered in the analysis were divided into three categories: ground-based equipments, airborne equipments, and aircraft landing systems.

In selecting ground-based equipments and aircraft landing systems for analysis, an area was established around each proposed ASDE-3 site, beyond which negligible interference could be expected to and from environmental equipment. Within this area, the existing and planned deployments of C&E equipments in or adjacent to the 15.7-17.7 GHz frequency band were determined from the ECAC data base. The ECAC data base was also used to select airborne equipments using the 15.7-17.7 GHz band in the U.S. Users were grouped according to types of equipments.

Equipments constituting the site environments were analyzed individually with respect to a typical ASDE-3 design to determine mutual interference potential. Potential problems were identified by considering required FDR (frequency-dependent rejection) and available frequency separations between a typical ASDE-3 radar and the airborne equipments.

SECTION 2

ANALYSIS

SYSTEM DESCRIPTION

The proposed frequency band for ASDE-3 (15.7-17.7 GHz) is allocated to the radiolocation service within the United States. The Office of Telecommunications Policy (OTP) has recently modified footnote G59 of the National Table of Frequency Allocations to read as follows: "In the band . . . 15.7-17.7 GHz all Government non-military radiolocation shall be secondary to military radiolocation, except in the sub-band 15.7-16.2 GHz, ASDE is permitted on a co-equal basis subject to coordination with the military departments."[2] According to the specifications, ASDE-3 must be designed and developed to be capable of tuning in a continuous manner over the 15.7-16.2 GHz band and over as much of the 16.2-17.7 GHz band as is economically feasible.

In the Request For Proposal, manufacturers were requested to submit design parameters for ASDE-3 radars operating on a single carrier frequency (no frequency-agility); such single-frequency systems are referred to as "basic" systems. Proposals for frequency-agile systems were also stated to be acceptable, and would be considered as "alternate" systems. TABLE 1 shows the technical characteristics of a typical "basic" system and a typical "alternate" system.

[2] *Manual of Regulations and Procedures for Radio Frequency Management,* Executive Office of the President, Office of Telecommunications Policy, Washington DC, May 1976.

TABLE 1

CHARACTERISTICS OF TYPICAL ASDE-3 RADARS

Type	Typical Basic System Single Frequency	Typical Alternate System Frequency Agile, 5 Hops, 30 MHz Each
Transmitter Tube	Magnetron	TWT
Peak Output Power (kW)	60	10
Pulse Width (ns)	36	36
PRF (kHz)	18 (staggered ≈0.15)	20
RX IF Frequency (MHz)	300	800
RX IF Bandwidth (MHz)	40	45
RX Noise Figure (dB)	10	6
Antenna Size (ft)	17.5 x 6	18 x 6
Antenna Gain (dBi)	46	47
Azimuth Beamwidth (degrees)	0.22	0.22
Vertical Beamwidth (degrees)	1	1
Vertical Pattern	csc	csc^x
Rotation Rate (r/min)	120	120

ASDE-3 radars are to be installed at thirty-three commercial airports in the U.S.[3]; the airports and coordinates are listed in TABLE 2. The radars are expected to be installed on top of existing control towers wherever possible and will utilize rotating antennas directed slightly downward to provide ground coverage within the area from 500 feet to 3 nmi from the antenna.

EMC ANALYSIS CONSIDERATIONS

ASDE-3 transmitter emission spectrums and receiver sensitivity to interfering signals are not provided in TABLE 1, and were determined by using other applicable technical characteristics of the ASDE-3 radars.

The emission spectrums were calculated using applicable pulse width (τ) and minimum allowable rise time (0.2τ) as indicated in the specification. The calculated spectrums for the typical basic and alternate systems are identical; Figure 1 is a plot of the spectrum.

ASDE-3 receiver sensitivity to interfering pulsed signals was assumed to be identical to the single-pulse threshold level for desired signals. Minimum threshold requirement (Reference 1) is detection of a single-pulse return at a signal-to-noise (S/N) ratio of 13 dB; however, to allow for design margin, the interference threshold was taken to be 10 dB S/N. Noise level was calculated based on thermal noise and receiver noise figure. For the narrowest receiver bandwidth given in TABLE 1 (40 MHz), thermal noise at room temperature is -98 dBm; since the noise

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[3] *FAA (ARD-61A) letter of March 17, 1976*, subject: Request to Permit Consideration of Frequency Agile and/or Pulse Compression Radar for ASDE.

TABLE 2

PROPOSED ASDE-3 LOCATIONS

Airport	Latitude deg	Latitude min	Latitude sec	Longitude deg	Longitude min	Longitude sec
Chicago (O'Hare)	41	58	57N	87	54	25W
Atlanta	33	38	31N	84	25	34W
New York	40	38	25N	73	46	41W
Los Angeles	33	56	32N	118	24	26W
New York (La Guardia)	40	46	36N	73	52	24W
San Francisco	37	37	07N	122	22	35W
Pittsburgh	40	29	37N	80	13	54W
Washington (National)	38	51	07N	77	02	28W
Denver	39	45	30N	104	52	57W
Boston	42	21	47N	71	00	19W
Philadelphia	39	52	12N	75	14	43W
Miami	25	47	39N	80	17	16W
St. Louis	38	44	54N	90	21	47W
Detroit	42	13	07N	83	20	55W
Cleveland	41	24	37N	81	50	56W
Newark	40	41	40N	74	10	08W
Minneapolis-St. Paul	44	53	03N	93	12	54W
Houston	29	59	08N	95	20	46W
Dallas (Love)	32	50	49N	96	51	12W
Dallas/Ft. Worth	32	53	49N	97	02	26W
Memphis	35	02	59N	89	58	44W
Honolulu	21	19	41N	158	03	06W
Tampa	27	58	25N	82	31	57W
Kansas City	39	18	05N	94	43	37W
New Orleans	29	59	31N	90	15	17W
Chicago (Midway)	41	47	04N	87	45	12W
Las Vegas	36	04	48N	115	09	08W
Seattle/Tacoma	47	26	55N	122	18	28W
Indianapolis	39	43	36N	86	16	59W
New York (Stewart)	41	30	17N	74	05	58W
Cincinnati	39	02	56N	84	39	53W
Phoenix	33	26	07N	112	00	43W
Portland	45	35	21N	122	35	33W

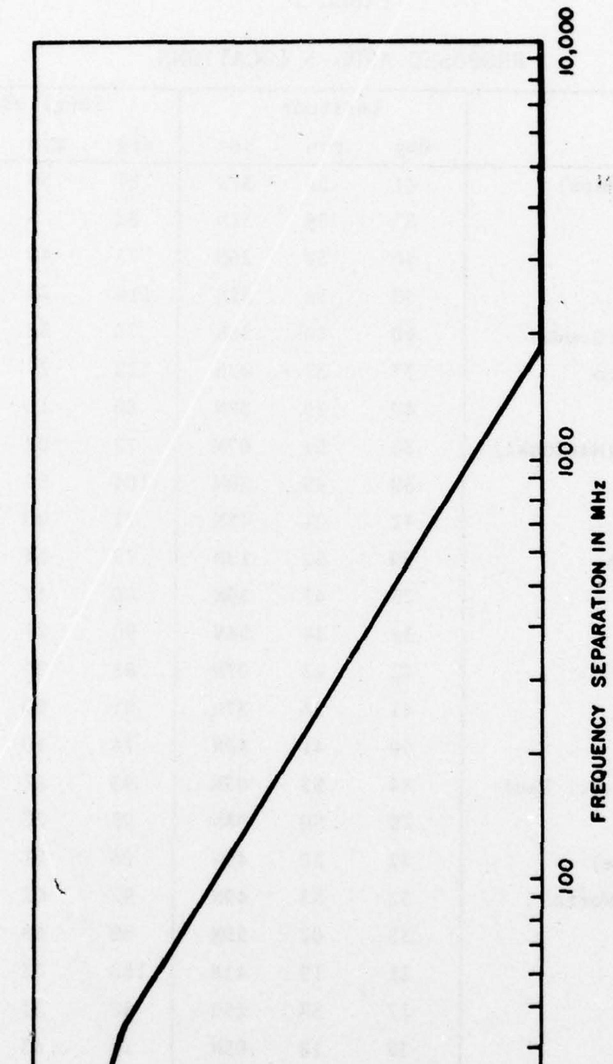

Figure 1. Calculated ASDE-3 emission spectrum.

figure is 10 dB and the required S/N is 10 dB, receiver sensitivity is -78 dBm (i.e., -98 + 10 + 10).

The ASDE specification also requires that 99% of transmitter power be contained within the ASDE-3 allocated band. To satisfy this requirement, ASDE-3 transmitter power at the band edge must be down approximately 20 dB from maximum. This 20-dB attenuation can be achieved if the ASDE-3 operates at least 60 MHz from the band edge (as shown in Figure 1).

Rejection of interference between the ASDE-3 and equipments in the environment was evaluated as a function of off-tuning of operating frequencies. Terms used in defining this rejection are:

FDR Frequency-Dependent Rejection (FDR) depends on the detuning and is the rejection provided by a receiver to a transmitted signal as a result of both the limited bandwidth of the receiver with respect to the emission spectrum and the specified detuning.

OTR On-Tune Rejection (OTR) is the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of the transmitter's emission spectrum exceeding the receiver bandwidth.

OFR Off-Frequency Rejection (OFR) is the rejection, over and above the OTR, provided by specified detuning of the receiver with respect to the transmitter. An example of an OFR curve is shown in Figure 2.

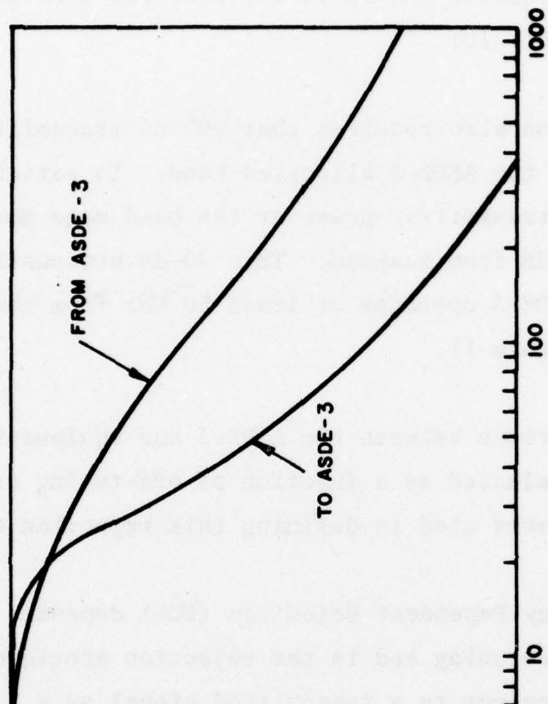

Figure 2. Typical off-frequency rejection curves.

FDR is thus the sum of OTR and OFR, when all terms are expressed in dB. A unique FDR is associated with each transmitter-receiver pair, and is dependent upon the spectrum and selectivity involved. Typical OFR curves are shown in Figure 2.

The single-frequency ASDE-3 described in TABLE 1 has a transmitter power which is 8 dB higher than the frequency-agile ASDE-3. In the analysis, however, the power levels of the two systems were both assumed to be 60 kW (the higher value), for simplicity of data presentation. Thus, calculations for the frequency-agile ASDE-3 system were identical to calculations for the single-frequency ASDE-3 system. Peak power interference calculations provide the same results for one channel of the frequency-agile systems as for the single-frequency system; the PRF of the interference is reduced by the number of channels, but peak power is not affected (e.g., the PRF per channel of the alternate system is 4000 pps, whereas the PRF of the basic system is 18000 pps). The average power per channel is reduced by using frequency agility, but the potential victims in the environment (other radars, aircraft landing system) will be susceptible to peak interference power as well as average interference power.

In utilizing the results of the calculations where interference is possible between the ASDE-3 radar and an equipment in the environment, the calculated frequency separation from the frequency-agile ASDE-3 is the separation from the center frequency of the closest ASDE channel. The frequency separation requirements and the operating frequencies of equipments in the environment were used to determine the frequency range available to ASDE-3, considering that the total range required by the agile

ASDE-3 system is the difference between the highest channel and the lowest channel (120 MHz). A determination was made whether the total spectrum requirement was available.

Three categories of equipments in the environment: ground-based equipments, airborne equipments, and adjacent-band aircraft landing systems, were considered in the analysis.

GROUND-BASED ENVIRONMENT

Analysis Method

ECAC data base files were searched for ground-based C&E equipment located within 100 miles of each proposed ASDE-3 site. The frequency bands considered were: adjacent band, 15.4-15.7 GHz; co-equal band, 15.7-16.2 GHz; secondary band (and adjacent to co-equal band), 16.2-17.7 GHz; and second harmonic band, 31.4-35.4 GHz. Technical characteristics of the equipments in the environment were determined from the ECAC Nominal Characteristics File (NCF) and are listed in TABLE 3.

Calculations were performed to determine the potential interference from the ASDE-3 transmitters to receivers in the environment, and to ASDE-3 receivers from transmitters in the environment. The level of interference power at the potential victim receiver was calculated from the following equation:

$$P_i = P_t + G_c - L_p - OTR - OFR \quad (1)$$

TABLE 3

TECHNICAL CHARACTERISTICS OF GROUND-BASED EQUIPMENTS

Nomenclature	Frequency (GHz)	Mod.	Peak Power Output (kW)	Pulse Width (μs)	Rise Time (μs)	Fall Time (μs)	Emission Bandwidth (MHz)	IF Bandwidth (MHz)	Antenna Gain (dBi)	Receiver Sensitivity (dBm)	Polar.[b]	System Description
SG-58 A/U	15.7-17.5	PO	125.0	0.4	.3	.35	2	-	17	-	C	Pulse generator
AN/APS-113	15.4-15.6	PO	10	1.5	.75	1.2	0.6	1.3	30	-100	C	Weather mapping radar
AN/MPQ-4	16.0	PO	50	0.25			3.6	5.0	44	- 96	H/C	National Guard training equipments
AN/GSN-5A	33.0-33.4	PO	50	0.2	.07[a]	.07[a]	4.5	14.0	49	- 96	L/C	Landing control system
AN/TPQ-11	34.5-35.2	PO	80	0.5	.05[a]	.05[a]	1.8	2.0	52	-120	H	Cloud detecting radar
AN/PPS-5	16.0-16.5	PO	1.0	0.25	.07	.14	3.6	5.0	40	- 95	H	Battlefield surveillance radar
SAD	16.3	P9	35	0.5	.05[a]	.05[a]	1.8[a]	2.0[a]	40[a]	- 91		Tracking radar (Sandia Labs)
RDR 110	15.4-15.6	PO	10	1.5	.75	1.2	0.6	1.3	30	-100	C	Weather radar
AN/SPN-42	32.9-33.5	PO	50	0.2	.07	.08	5.0	16.0	48	- 96	V/C	Landing control system
108 K (Vega)	15.72-15.73	PO	1.2	0.5	.5	.1	3.0	54	30	- 65	V	Tracking radar
322 K (Vega)	15.725	PO	1.2	0.5	.05	.1	3.0	27	2.1	- 65	V	Transponder used with 108 K
Equipment A												Classified equipment characteristics
Equipment B												"
Equipment C												"
None	31.4	AO						500	76.4		C	Radio Astronomy Observatory
None	26.5-40.0	AO						10	78.5		C	"
None	16.2	AO						1000	69.4		L	"
None	34.5	AO						20	38.0		L	"
None	35.0	AO						500	79.5		C	"

[a]Estimated values.

[b]C-Circular
H-Horizontal
V-Vertical

where

P_i = peak interference power at the victim antenna terminals, in dBm

P_t = peak transmitter power, in dBm

G_c = antenna gain coupling, in dBi

L_p = propagation path loss, in dB

OFR = off-frequency rejection, in dB

OTR = on-tune rejection, in dB.

In calculating interference power at ASDE-3 harmonic frequencies, harmonic attenuation was assumed to be 60 dB, in accordance with the ASDE-3 specification. Antenna gain coupling (G_c) was calculated by considering ASDE-3 mainbeam gain and estimated side-lobe gain of 0 dBi for environmental equipments. This procedure was taken because ASDE-3 gain is at a maximum in the direction of the horizon, and the antenna is likely to illuminate ground-based equipments, while environmental equipments are generally tracking type radars that are not likely to be directed toward ASDE-3 radars. Propagation path loss was calculated between each ASDE-3 location and nearby environmental equipment using a terrain-dependent ECAC path loss model; antenna heights for environmental equipments were obtained from the ECAC data base, and ASDE-3 antenna heights were assumed to be equal to the control tower height at the airport location. OFR and OTR were calculated using the characteristics of the ASDE-3 radar (TABLE 1) and the equipments located near the ASDE-3 sites (listed in TABLE 3).

Initially, the level of interference power (P_i) to the ASDE-3 and from the ASDE-3 was calculated from Equation 1, using 0-dB OFR. If P_i exceeded receiver sensitivity (R_s), a calculation was made to determine the OFR required to reduce the interference power to the receiver sensitivity level, and the required frequency separation (Δf) was determined. R_s for ASDE was previously calculated to be -78 dBm, and R_s values for the environmental equipments listed in TABLE 3 were obtained from the data base (with the exception of Radio Astronomy systems). Sensitivity of Radio Astronomy systems was calculated according to CCIR methods, using the following equations[4]:

$$\Delta T_e = \frac{T_e}{\sqrt{2Bt}} \qquad (2)$$

$$\Delta P_H = -208.6 + 10 \log B + 10 \log (\Delta T_e) \qquad (3)$$

where

B = the receiver bandwidth, in Hz

t = the total time of the observation, in seconds

T_e = the operating noise temperature, in K

ΔT_e = the temperature sensitivity, in K

ΔP_H = a minimum harmful input power, in dBm.

[4] *Factors Affecting the Possibility of Frequency Sharing Between Radio-Astronomy and Other Services,* Report 224-3, CCIR, 1974.

Potential Interference Path Calculations

The EMC analysis of ground-based equipments showed that, of the thirty-three proposed locations for ASDE-3, only thirteen have C&E equipments operating in the frequency bands of concern located within a 100-mile radius. Calculations of interference power level were made for these thirteen airports, and results are summarized in TABLES 4, 5, and 6. The first two columns in TABLES 4 and 5 show the airports proposed for ASDE-3 operational deployment, and identify C&E equipments located near these airports. The third and fourth columns list the operating frequency ranges of C&E equipments and their locations, and the L_p values listed in the fifth column are based on terrain-dependent models. Peak interference power listed in the sixth column is calculated assuming a 0-dB OFR (on-tune operation). The required OFR and required frequency separations between ASDE-3 radars and equipments in the environment are listed in the last two columns. TABLE 6 is similar to TABLES 4 and 5, except that the radio astronomy receivers interference is presented for comparison with the available loss between the observatory and the nearby ASDE-3 location.

Of the thirteen airports listed in TABLES 4, 5, and 6, calculations indicate that interference is possible (both to ASDE-3 and from ASDE-3) at the following locations: Honolulu, Miami, Las Vegas, Portland. Also, interference from the ASDE-3 to radio astronomy observatories is possible at Detroit and Boston. Interactions at each of these locations are discussed in the following paragraphs.

Honolulu. An AN/PPS-5 is authorized to operate statewide in Hawaii, and was assumed to be operating within 3 nmi of the ASDE-3

TABLE 4

CALCULATIONS OF POTENTIAL INTERFERENCE TO ASDE-3 RADARS

Proposed ASDE-3 Location	Equipment Located Near ASDE-3 Sites						
	Nomenclature	Frequency Range (GHz)	Location	L_p (dB)	P_i (dBm)	Required OFR (dB)	Required Δf (MHz)
Philadelphia	AN/MPQ-4	16.0	Moorestown, NJ	213.0	- 90	0	0
Seattle	AN/MPQ-4	16.0	Yakima, WA	253	-130	0	0
	AN/MPQ-4	16.0	Ft. Lewis, WA	204	- 81	0	0
	AN/PPS-5	16.0-16.5	Port Angeles, WA	209	-105	0	0
Honolulu	AN/PPS-5	16.0-16.5	Hawaii (statewide)	151	- 45	33	44
	SAD	16.3	Barbers Point, HI	135	- 13.1	64.9	158
	SAD	16.3	Hickam AFB, HI	137	- 15.1	62.9	141
	EQUIP. A[a]		Kaneohe MCAS, HI	199	- 73	5	22
Miami	RDR 110	15.4-15.6	Fort Lauderdale, FL	191	- 80	0	0
	EQUIP. B[a]		Carol City, FL	141	- 14	64	281
	" "		Key Largo, FL	207	- 80	0	0
	" "		Florida City, FL	209	- 82	0	0
	" "		S. Miami, FL	144	- 17	61	224
	EQUIP. A[a]		Miami, FL	159	- 33	45	64
	" "		Miami, FL	195.5	- 69.5	8.5	24
	" "		Miami, FL	158	- 32	46	72
	" "		Boca Chica, FL	244.3	-118.3	0	0
	" "		Geiger Key, FL	243	-117	0	0
	" "		Key West, FL	249	-123	0	0
	" "		Fleming Key, FL	242	-116	0	0
	" "		Miami, FL	148	- 22	56	100
Las Vegas	EQUIP. C[a]		Nellis AFB, NV	143	- 34	44	70
	108 K (Vega)	15.725	Nellis AFB, NV	150	- 43	35	35
	322 K (Vega)	15.725	Nellis AFB, NV	150	- 43	35	35
Dallas	SG-58A/U	16.6	Majors Field, TX	223.0	- 96	0	0
Washington	AN/APS-113	15.6-15.7	Greenbelt, MD	161.7	- 45.3	32.7	30
Portland	AN/MPQ-4	16.0	Portland, OR	127.0	- 4	74	600

[a]Technical characteristics of these equipments are classified.

TABLE 5

CALCULATIONS OF POTENTIAL INTERFERENCE FROM ASDE-3 RADARS

Proposed ASDE-3 Location	Equipment Located Near ASDE-3 Sites						
	Nomenclature	Frequency Range (GHz)	Location	L_p (dB)	P_i (dBm)	Required OFR (dB)	Required Δf (MHz)
Philadelphia	AN/MPQ-4	16.0	Moorestown, NJ	213.0	-106	0	0
	AN/GSN-5A	34.5-35.2	Lakehurst, NJ	233.0	-165.4	0	0
	AN/GSN-5A	34.86	Lakehurst, NJ	231.0	-164.4	0	0
Newark	AN/GSN-5A	34.5-35.25	Lakehurst, NJ	231.0	-164.4	0	0
New York (La Guardia)	AN/GSN-5A	34.5-35.25	Lakehurst, NJ	231.0	-164.4	0	0
	AN/GSN-5A	34.5-35.25	Lakehurst, NJ	235.0	-169.0	0	0
Seattle	AN/MPQ-4	16.0	Yakima, WA	253.0	-144.0	0	0
	AN/TPQ-11	34.5-35.2	McChord AFB, WA	176.0	-135.0	0	0
	AN/PPS-5	16.0-16.5	Port Angeles, WA	209.0	-100.0	0	0
	AN/MPQ-4	16.0	Ft. Lewis, WA	204.0	- 95	0	0
Honolulu	AN/PPS-5	16.0-16.5	Hawaii (statewide)	151.0	- 42.0	53	500
	SAD	16.3	Barbers Point, HI	135.0	- 34.0	57	560
	SAD	16.3	Hickam AFB, HI	137.0	- 36.0	55	450
	EQUIP. A[a]		Kaneohe MCAS, HI	199.0	-102.0	0	0
Memphis	AN/SPN-42	33-33.4	Memphis, TN	191.0	-125	0	0
Miami	RDR 110	15.4-15.6	Fort Lauderdale, FL	191.0	- 83.0	17	70
	EQUIP. B[a]		Carol City, FL	141.0	- 33.0	72	1400
	" "		Key Largo, FL	207.0	- 96.0	9	31
	" "		Florida City, FL	209.0	- 98.0	7	22
	" "		S. Miami, FL	144.0	- 36.0	69	1200
	EQUIP. A[a]		Miami, FL	159.0	- 62.0	40	200
	" "		Miami, FL	195.5	- 98.0	4	15
	" "		Miami, FL	158.0	- 51.0	51	370
	" "		Boca Chica, FL	244.3	-149.9	0	0
	" "		Geiger Key, FL	243.0	-146.0	0	0
	" "		Key West, FL	249.0	-152.0	0	0
	" "		Fleming Key, FL	242.0	-145.0	0	0
	" "		Miami, FL	148.0	- 41.0	61	400
Las Vegas	EQUIP. C[a]		Nellis AFB, NV	143.0	- 47.6	28.4	10
	108 K (Vega)	15.725	Nellis AFB, NV	150.0	- 29.0	36	200
	322 K (Vega)	15.725	Nellis AFB, NV	150.0	- 29.0	36	200
Washington	AN/APS-113	15.6-15.7	Greenbelt, MD	161.7	- 64.3	35.7	158
Portland	AN/MPQ-4	16.0	Portland, OR	127.0	- 18	78	1700

[a] Technical characteristics of these equipments are classified.

TABLE 6

CALCULATIONS OF POTENTIAL INTERFERENCE FROM ASDE-3 TO RADIO ASTRONOMY OBSERVATORIES (RAO)

Proposed ASDE-3 Location	RAO Location	Frequency Range (GHz)	ΔT_e (K)	ΔP_H (dBm)	Required L_p (dB)	Available L_p (dB)	Remarks
Washington	Riverside, MD	31.4	1.4×10^{-3}	-150.1	219.1	228.0	No interference
Washington	Riverside, MD	26.5-40	1.5×10^{-2}	-156.8	220.8	228.0	No interference
Detroit	Dexter, MI	16.2	5×10^{-4}	-151.6	275.6	193.5	See text
Boston	Hamilton, MA	34.5	1.06×10^{-2}	-155.6	219.6	160.0	See text
Boston	Tyngsboro, MA	35.0	1.8×10^{-3}	-149.1	213.0	175.0	See text

location because of military property proximity to the airport. Two fixed-frequency tracking radars are also located in this area. In order to avoid EMC problems, an acceptable operating frequency range for ASDE is 17.02-17.7 GHz.

Miami. Numerous Army radars operate in the vicinity. The acceptable operating frequency range for ASDE-3 is 15.7-16.0 GHz, assuming that Army equipment in the 15.7-16.2 GHz co-equal band can be retuned to assure compatibility.

Las Vegas. Nellis AFB test range equipment is potentially incompatible with the ASDE-3, depending on frequency separation. The acceptable frequency range for the ASDE-3 is 15.92-16.2 GHz.

Portland. An AN/MPQ-4 radar, operated by the National Guard, is within 3 nmi of the Portland control tower. Required frequency separation is 1.7 GHz (see TABLE 5) between the ASDE-3 and this fixed-tuned equipment. Insufficient tuning range is available to avoid interference; operational coordination is likely to be required at this location.

Detroit. Radio astronomy observations at 16.2 GHz may detect interference from an ASDE-3 at the Detroit airport. However, 16.2 GHz is not allocated to the radio astronomy service, and protection of observations at this frequency is not required.

Boston. Radio astronomy observations at 34.5 and 35.0 GHz may detect interference from ASDE-3 second harmonic emissions. However, 34.5 and 35.0 GHz are not allocated to the radio astronomy service, and protection of observations at these frequencies is not required.

Coordination Requirements

At Honolulu, Miami, and Las Vegas, frequency coordination with equipments in the environment will be required, in that the ASDE-3 will be required to operate in a specified portion of the 15.7-17.7 GHz band in order to avoid EMC problems, and some equipments in the environment will be required to retune in order to accommodate ASDE-3 use of the 15.7-16.2 GHz co-equal portion of the band. Since the single-frequency ASDE-3 radars as well as the frequency-agile ASDE radars are to be tunable, frequency coordination is a feasible solution to EMC problems. Also, the available frequency ranges for ASDE-3 (17.0-17.7 GHz at Honolulu, 15.7-16.0 at Miami, 15.92-16.2 at Las Vegas) are sufficiently large to allow operation of the frequency-agile system.

At Portland, operational coordination is likely to be required regardless of whether a single-frequency ASDE or a frequency-agile ASDE-3 is used.

AIRBORNE EQUIPMENTS IN 15.7-17.7 GHZ BAND

In order to identify the present and planned uses of the 15.7-17.7 GHz band by airborne equipments, various files within the ECAC data base were searched: the Nominal Characteristics File (NCF), the Organization Platform Allowance File (OPAF), and the Future File. The list of equipments thus generated was reduced by eliminating experimental-only equipments, equipments no longer used on current aircraft (as reflected in the OPAF file), equipments used outside of CONUS or Hawaii, and equipments scheduled for replacement before 1980. Two final lists of equipments were compiled, one

classified and the other unclassified; the unclassified list is presented in TABLE 7.

The information in TABLE 7 indicates that all airborne users are U.S. military fixed-wing aircraft of the fighter, fighter-bomber, or tanker classes. The classified list of equipments contains approximately the same number of equipments types, which are used by the same type of aircraft classes. Because of similarity in technical characteristics, the airborne users of the 15.7-17.7 GHz band may be grouped into three categories: attack/bomb/fire-control radars, terrain-following radars, and beacon transponders. Technical characteristics of the three equipment categories are listed in TABLE 8.

Potential Interference Between ASDE-3 and Airborne Equipments

The airborne users of the 15.7-17.7 GHz band all operate within the range from 16.0 to 17.1 GHz. The primary consideration is to determine compatibility of ASDE-3 with these equipments when ASDE-3 operates in the 15.7-16.2 GHz range. Since some degree of off-tuning will usually exist between an ASDE-3 and an airborne equipment, interference can be prevented by a combination of off-frequency rejection (OFR) and distance separation between equipments. In order to determine the distance required between equipments, the required propagation loss (L_p) was calculated using the following equation and was converted to distance by use of the free-space path loss formula, unless otherwise indicated:

$$L_p = P_t + G_t + G_r - OFR - OTR - R_s \quad (4)$$

TABLE 7

AIRBORNE EQUIPMENTS (UNCLASSIFIED ONLY) IN 15.7-17.7 GHz BAND

Equipment Type	Equipment Nomenclature	Operating Frequency	Use
Attack Radar (F-111 Aircraft)	AN/APQ-113 (F-111A, F-111E) AN/APQ-114 (FB-111A) AN/APQ-130 (F-111D) AN/APQ-144 (F-111F)	Pulse-to-pulse frequency agile throughout 16.0-16.4 GHz band.	Search and lock-on of airborne targets.
Bomb Directing Set (RA-5C Aircraft)	AN/ASB-12	Continuously tunable by operator throughout 16.0-17.0 GHz band.	Tracking of ground targets forward of aircraft on bombing runs.
Terrain-Following Radar (F-111 Aircraft)	AN/APQ-110 (F-111A, F-111E) AN/APQ-128 (F-111D) AN/APQ-134 (FB-111A) AN/APQ-146 (F-111F)	Continuously tunable by maintenance personnel throughout 16.6-17.1 GHz band.	Provides inputs to aircraft flight-control system to maintain aircraft altitude at 200 to 1000 feet above the ground.
Terrain-Following Radar (RF-4B and RF-4C Aircraft)	AN/APQ-99	Fixed frequency, 16.5 (+0.125, -0.09) GHz.	Provides inputs to aircraft flight-control system to maintain aircraft altitude at 200 to 1000 feet above the ground.
Beacon Transponder (KC-135 Aircraft)	AN/APN-134	Fixed frequency: 16.28 GHz receive, 16.50 GHz transmit.	Replies to interrogations of KU-band radars utilizing a pulse width of 2 ± 0.7 μs.

TABLE 8

TECHNICAL CHARACTERISTICS OF AIRBORNE EQUIPMENTS

Characteristics	Attack/Bomb/Fire-Control Radars	Terrain-Following Radars	Beacon Transponders
Peak Transmitter Power (kW)	60	60	2
Minimum Pulse Width (μs)	0.4	0.2	0.75
Emission Spectrum (MHz)			
-3 dB	± 1.25	± 2.5	± .67
-20 dB	± 8	± 16	± 4.2
-80 dB	± 250	± 500	± 130
Receiver Sensitivity (dBm)	- 100	- 92	- 66
Receiver Selectivity (MHz)			
-3 dB	± 2.5	± 4	± 40
-20 dB	± 5	± 10	± 65
-60 dB	± 12.5	± 22.5	± 72.5
Antenna Gain (dBi)	30	33	8

where

G_t = the transmitter antenna gain, in dBi

G_r = the receiver antenna gain, in dBi

R_s = the receiver sensitivity, in dBm

and other terms have previously been defined.

OFR and OTR were calculated using the characteristics of the ASDE-3 (TABLE 1) and of the equipments in TABLE 8. Since the ASDE-3 is assumed to be operating within the 15.7-16.2 GHz band, and the maximum ASDE-3 frequency is at least 60 MHz below the band edge, regardless of whether single-frequency or frequency-hopping is used, the maximum ASDE-3 frequency is 16.14 GHz. Difference frequency for OFR is generally the difference between the airborne equipment frequency and 16.14 GHz. The receiver sensitivity (R_s) value is that listed in the NCF for desired signals. Since the ASDE-3 antenna gain toward the horizon and low elevation angles is significant, the antenna is likely to illuminate aircraft within line-of-sight, and the mainbeam ASDE-3 gain is used in the calculations; since the aircraft antennas are highly directional and probably will not illuminate the ASDE-3, an estimated far-sidelobe gain of 0 dBi is used.

Potential Interference to ASDE-3 Radars

Attack/Bomb/Fire-Control Radars. With the exception of the F-111 Attack Radar, the attack/bomb/fire-control radars are tunable throughout the 16-17 GHz band. The F-111 Attack Radar is frequency-agile from 16.0-16.4 GHz. In the case of on-tune interference to an ASDE-3, in the 16.0 to 16.16 GHz range:

$$L_p = 78 + 0 + 46 - 0 - 0 - (-78)$$
$$= 202 \text{ dB.}$$

This propagation loss can be achieved *only* if the aircraft is beyond line-of-sight (LOS) from an ASDE-3. Hence, in the case of F-111 attack radar operation and when the other attack/bomb/fire-control radars operate in the 16.0-16.14 GHz range, the ASDE-3 threshold will be exceeded once per sweep when the ASDE-3 antenna is pointed at the aircraft.

When the tunable radars operate just above the 15.7-16.2 GHz "co-equal" range (at 16.2 GHz), frequency separation from the ASDE-3 will be 60 to 440 MHz. OFR at a separation of 250 MHz or greater will be approximately 70 dB, and the required loss will be:

$$L_p = 78 + 0 + 46 - 70 - 0 - (-78)$$
$$= 132 \text{ dB}$$

This propagation loss can be achieved at a distance of 3 nmi between an ASDE-3 and an aircraft. Since military aircraft training areas are not generally located in the vicinity of commercial airports, a 3-nmi separation will generally be available and no interference will occur if frequency coordination is utilized.

In the case of the frequency-agile F-111 radar, OFR can be increased only if the ASDE-3 operates at the low end of its range. At 15.76 GHz, OFR between the F-111 radar and the ASDE-3 will be approximately 70 dB, and the 3-nmi distance above is applicable.

In general, since frequency coordination within the 15.7-16.2 GHz range can prevent interference to the ASDE-3 at distances as close as 3 nmi, this is a manageable problem.

Terrain-Following (TF) Radars. Minimum operating frequency for the TF radars is 16.5 GHz. The difference frequency between 16.5 GHz and the ASDE-3 at 16.14 GHz is 360 MHz and OFR is approximately 67 dB.

$$
\begin{aligned}
L_p &= 78 + 0 + 46 - 67 - 0 - (-78) \\
&= 135 \text{ dB.}
\end{aligned}
$$

This loss corresponds to a 5-nmi separation. Since it is unlikely that military aircraft will be operating in the low altitude TF mode within 5 nmi of major commercial airports, this is a negligible problem.

Beacon Transponders. The beacon transmit frequency is 16.5 GHz. Separation from an ASDE-3 at 16.14 GHz is 360 MHz and OFR is approximately 70 dB.

$$
\begin{aligned}
L_p &= 63 + 0 + 46 - 70 - 1 - (-78) \\
&= 116 \text{ dB.}
\end{aligned}
$$

Since this loss is achieved at less than 1-nmi separation, this is a negligible problem.

Potential Interference from ASDE-3 Radars

Attack/Bomb/Fire-Control Radars. In the case of frequency-agile attack/bomb/fire-control radars operating in the 16.0-16.4

GHz range, the maximum possible frequency separation from an ASDE-3 in the 15.7-16.2 GHz range is 240 MHz (16.0-15.76 GHz) and OFR is 44 dB. The required propagation loss is:

$$L_p = 78 + 46 + 0 - 44 - 9 - (-100)$$
$$= 171 \text{ dB.}$$

This loss will be exceeded only beyond line-of-sight.

In the case of 16-17 GHz tunable attack/bomb/fire-control radars, if the airborne radar is tuned just above the "co-equal" band, the maximum possible frequency separation from ASDE-3 is 440 MHz (16.2-15.76 GHz), and OFR is 54 dB. The required loss is:

$$L_p = 78 + 46 + 0 - 54 - 9 - (-100)$$
$$= 161 \text{ dB.}$$

This loss will be exceeded at a distance of 90 nmi or greater. Thus, the ASDE-3 signal will exceed the sensitivity of the attack/bomb/fire-control radars at large distance separations even if frequency use is coordinated in the 15.7-16.2 GHz band. Interference to aircraft radar receiver operation will depend on the receiver processing and display methods, which are somewhat elaborate in order to account for various modes of operation, pulse widths, frequency agility, etc.

This problem should be investigated further in order to identify aircraft training areas and to perform airborne receiver degradation analysis.

Terrain-Following Radars. Considering the minimum frequency separation of 360 MHz:

$$L_p = 78 + 46 + 0 - 51 - 7 - (-92)$$

$$= 158 \text{ dB}.$$

This propagation loss between an ASDE-3 antenna at a 100-foot elevation and an aircraft at a 600-foot elevation (median for TF mode) will be exceeded at distances greater than 40 nmi, even assuming that no terrain obstructions exist between the ASDE-3 and the aircraft. Since military aircraft are not likely to utilize the TF mode within this distance of large commercial airports, this is a negligible problem.

Beacon Transponders. Beacon transponders will reply only to pulses having a pulse width in the range from 1.3 to 2.7 μs. Since the ASDE-3 pulse width will be approximately 0.04 μs, no interference will occur, and this is a negligible problem.

ADJACENT-BAND AIRCRAFT LANDING SYSTEMS

The 15.4-15.7 GHz band is adjacent to the portion of the ASDE-3 band in which co-equal operation with military systems is permitted; i.e., 15.7-16.2 GHz. Several aircraft landing systems are in operation or planned for the 15.4-15.7 GHz band; possible interactions of these systems with ASDE-3 are considered in the following paragraphs.

Microwave Landing System (MLS)

The format for the MLS, developed by the Radio Technical Commission for Aeronautics Special Committee -117 (RTCA SC-117), included provisions for aircraft flare guidance in the 15.4-15.7 GHz band (Ku-band). Several proposals for the MLS included flare guidance in Ku-band, but some MLS proposals restricted frequency usage to the 5.0-5.25 GHz range (C-band). Presently, the International Civil Aviation Organization (ICAO) is evaluating two proposals in order to decide on the international system. The US proposal[5] states that "C-band is the appropriate choice over Ku-band for flare guidance," and proposes all MLS operations in the 5.0-5.25 GHz band. The United Kingdom proposal[6] states that the "Doppler system will provide flare guidance at C-band," and also restricts MLS frequencies to the 5.0-5.25 GHz range.

Since the Ku-band is not presently under active consideration for use in the international MLS system, no interactions with ASDE-3 were investigated.

Aircraft Approach Control System (AACS)

The US Navy operates AACS equipments on board certain aircraft carriers, and at Naval Stations at the following locations: Lemoore, CA; Miramar, CA; Edwards, CA; Fentress, VA; Whidbey Island, WA; Cecil Field, FL; and San Clemente, CA.

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[5] *Time Reference Scanning Beam MLS,* submitted to ICAO by the United States. FAA, December 1975.

[6] *Doppler Microwave Landing Guidance System,* submitted to ICAO by the United Kingdom, November 1975.

The AACS uses a ground-based transmitter, the AN/SPN-41 or AN/TRN-28, to provide azimuth and elevation signals to landing aircraft equipped with AN/ARA-63 receivers. Technical characteristics of AACS equipment are provided in TABLE 9.

Two interactions of the AACS with the ASDE-3 are possible: AACS ground transmitter interference to ASDE-3, and ASDE-3 transmitter interference to airborne AACS receivers.

Frequency Separation. It was previously indicated that the proposed ASDE-3 designs must operate at least 60 MHz from the band edge (15700 MHz), in order to comply with the ASDE-3 specification. The ASDE-3 operating frequency closest to the 15.4-15.7 GHz band will thus be 15760 MHz. Since the highest AACS operating frequency is 15688 MHz, the minimum frequency separation between an ASDE-3 radar and an AACS equipment will be 72 MHz.

Interference to ASDE-3. Both the AACS transmitter and the ASDE-3 radar are ground-based equipments; interference to the ASDE-3 receiver will be avoided if they are sufficiently far apart to allow AACS power to be less than the ASDE-3 receiver sensitivity. Propagation loss required to achieve this condition may be calculated from the following equation:

$$L_p = P_t + G_c - FDR - R_s \qquad (5)$$

where

FDR = the frequency dependent rejection, in dB (the sum of OFR and OTR in dB).

TABLE 9

AACS TECHNICAL CHARACTERISTICS

TRANSMITTER (AN/SPN-41 OR AN/TRN-28)	
Frequency (MHz)	15412, 15436, 15484, 15508, 15536, 15568, 15592, 15616, 15664, or 15688
Peak Output Power (kW)	2.5
Pulse Width (μs)	0.3
Pulse Rise Time (μs)	0.05
Pulse Rate	pulse pairs, 10 to 15 μs interpulse, 60 to 100 μs interpair
Antenna Polarization	vertical
Azimuth Antenna	31 dBi gain, scans ±20^{o}
Elevation Antenna	25 dBi gain, scans 0^{o} to +10^{o}
RECEIVER (AN/ARA-63)	
Frequency	selectable, same as transmitter at desired landing area
IF Bandwidth (MHz)	10
Noise Figure (dB)	10
Antenna Polarization	vertical
Antenna Gain (dBi)	4

For mainbeam-to-mainbeam antenna gain conditions, gain coupling will be (46 + 31 - 3 = 74 dB), allowing for a 3-dB linear-to-circular polarization loss. FDR of the ASDE-3 receiver to the AACS transmitter emission was calculated to be 42 dB, using an existing ECAC model; the receiver threshold was previously stated as -78 dBm. The required propagation loss is thus:

$$L_p = 64 + 74 - 42 - (-78)$$
$$= 174 \text{ dB.}$$

Propagation loss between a ground-based AACS antenna (6-ft elevation) and an ASDE-3 antenna (100-ft elevation) will exceed 174 dB at a distance of 18 nmi. No AACS ground transmitters (AN/TRN-28) are presently located within 18 nmi of a proposed ASDE-3 location. Propagation loss between a ship-based AACS antenna (70-ft elevation) and an ASDE-3 antenna (100-ft elevation) will exceed 174 dB at a distance of 25 nmi. Thus, interference to the ASDE-3 is possible under worst-case tuning conditions and worst-case antenna coupling conditions if an aircraft carrier is conducting flight operations within 25 nmi of an ASDE-3 equipped airport.

Since the AACS antennas are directed only toward the approach path, a more probable antenna coupling would be the AACS far side-lobe to the ASDE-3 mainbeam. Gain coupling in this case would be (0 + 46 = 46 dB).

$$L_p = 64 + 46 - 42 - (-78)$$
$$= 146 \text{ dB.}$$

Path loss will exceed 146 dB when the aircraft carrier is more than 16 nmi from the ASDE-3. Since it is unlikely that carrier operations are carried out within 16 nmi of a major airport, ASDE-3 radars should not be affected by AACS transmissions.

Interference from ASDE-3. As in the preceding paragraphs, the minimum ASDE frequency is 15760 MHz, the maximum AACS frequency is 15688 MHz. FDR of the AN/ARA-63 receiver to ASDE-3 emissions was calculated to be 32 dB at this frequency separation. An aircraft receiving AACS signals will be at a maximum altitude of approximately 20,000 feet, and at this altitude will be within line-of-sight of ASDE-3 radars up to 200 nmi away. The receiver noise level of the AN/ARA-63 was calculated to be -94 dBm at room temperature, considering the IF bandwidth of 10 MHz and noise figure of 10 dB. For mainbeam-to-mainbeam conditions, gain coupling is (46 + 4 - 3 = 47 dB), allowing for a 3-dB polarization loss for circular-to-linear coupling. Required propagation loss is calculated:

$$L_p = 78 + 47 - 32 - (-94)$$

$$= 187 \text{ dB.}$$

This loss is not exceeded at the 200-nmi line-of-sight range, and the interference level will exceed the noise level of the receiver when the aircraft is within line-of-sight of an ASDE-3 radar, assuming the ASDE-3 mainbeam illuminates the aircraft. When the aircraft is in the ASDE-3 sidelobe, gain coupling will be (0 + 4 = 4 dB), and:

$$L_p = 78 + 4 - 32 - (-94)$$

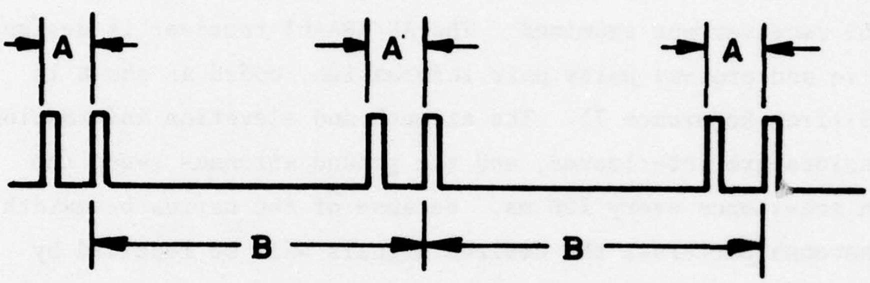
$$= 144 \text{ dB.}$$

Thus, receiver noise level will be exceeded within 13 nmi of an ASDE-3, in the ASDE-3 antenna sidelobe.

In order to determine the effect of the ASDE-3 interference power on the AACS, the processing of the AACS signals by the AN/ARA-63 receiver was examined. The AN/ARA-63 receiver is designed to receive and process pulse pair information, coded as shown in Figure 3 (from Reference 7). The azimuth and elevation information transmissions are interleaved, and the ground antennas sweep the approach areas once every 200 ms. Because of the narrow beamwidth of the antenna patterns, the desired signals will be received by the aircraft for short periods of time during each sweep; azimuth signals are received for approximately 12 ms each sweep, and elevation signals are received approximately 4.5 ms each sweep. In contrast to the desired signal at 5 sweeps/s, the interfering signal will be received twice per second, since only mainbeam ASDE-3 interference will predominate. The ASDE-3 horizontal beamwidth is 0.22 degrees; at 120 r/min, the aircraft will be illuminated for approximately 0.3 ms. Figure 4 shows the relationship of the desired signal to the undesired signal. The duration of a 36-ns interfering pulse in the AN/ARA-63 receiver will be the inverse of the receiver IF bandwidth (0.1 μs), and the interval between interfering pulses will be 55.5 μs.

Both the desired and undesired signals will be converted to an IF by the receiver and will be passed to the pulse decoder. The pulse decoder contains an "identity shift register" that is

[7] *Technical Manual, Receiving Decoding Group AN/ARA-63,* NAVAIR 16-30ARA63-1, Naval Air Systems Command, 15 March 1973, changed 15 June 1975.



A. IDENTITY SPACING

10 or 11 μs - Azimuth left
14 or 15 μs - Azimuth right
12 or 13 μs - Elevation

B. ANGLE SPACING

60 μs = 0-degree elevation
or runway centerline (azimuth)
2 μs per degree to maximum of
100 μs for 20 degrees

Figure 3. AACS pulse coding.

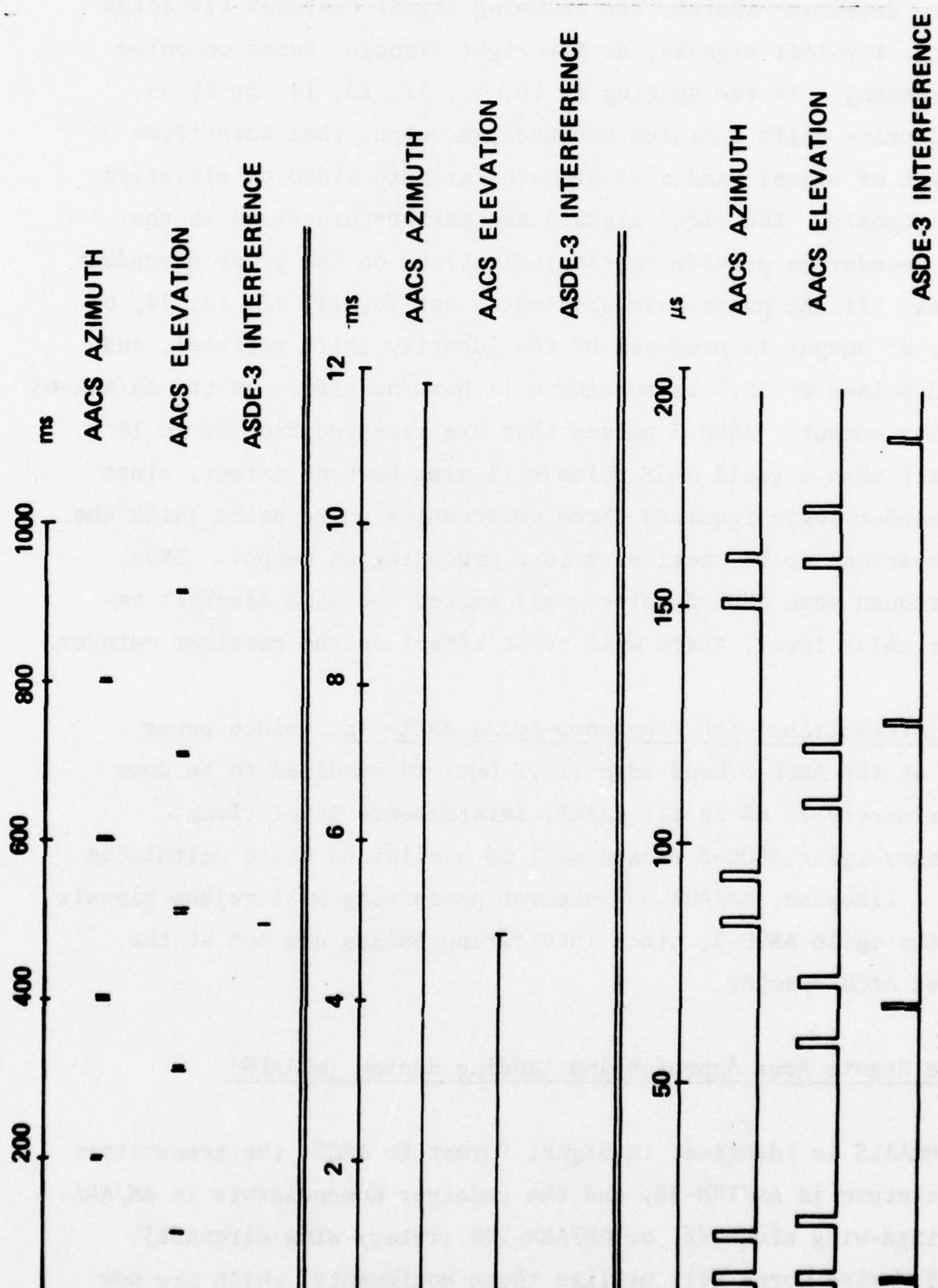


Figure 4. AACS and ASDE-3 signals in an AACS airborne receiver.

used to determine whether the incoming signal contains elevation signals, fly-left signals, or fly-right signals, based on pulse pair spacing. If the spacing is 10, 11, 12, 13, 14, or 15 μs, the identity shift register produces an output that identifies the type of signal, and also produces azimuth video or elevation video signals. The video signals are further processed in the pulse decoder to provide course indications on the pilot's readout devices. If the pulse-pair spacing is not 10, 11, 12, 13, 14, or 15 μs, no output is produced by the identity shift register, and ASDE-3 pulses at 55.5-μs spacing will have no effect an the AN/ARA-63 receiver output. ASDE-3 pulses that are received from 10 to 15 μs later than a valid AACS pulse will also have no effect, since the decoder logic required three consecutive pulse pairs (with the same spacing) to be received before producing an output. Thus, even though some ASDE-3 pulses will exceed the AACS aircraft receiver noise level, there will be no effect on the receiver outputs.

Interactions with Frequency-Agile ASDE-3's. Since power level at the ASDE-3 band edge (15.7 GHz) is required to be down approximately 20 dB in all cases, interference levels from frequency-agile ASDE-3 radars will be similar to those calculated above. Likewise, AN/ARA-63 receiver processing will reject signals from the agile ASDE-3, since interfering pulses are not at the desired AACS spacing.

Marine Remote Area Approach and Landing System (MRAALS)

MRAALS is identical in signal format to AACS; the transmitter nomenclature is AN/TRN-30, and the receiver nomenclature is AN/ARA-63 (fixed-wing aircraft) or AN/ARN-128 (rotary-wing aircraft). The US Marine Corps will utilize these equipments, which are now

being procured, in tactical situations as well as at bases in the US.[8] Marine Corps Air Stations are expected to be equipped with MRAALS; in the US, these air stations are located at Beaufort, SC; El Toro, CA; Kaneohe, HI; New River, NC; Quantico, VA; Santa Ana, CA; and Yuma, AZ; Camp Pendleton, CA; and Cherry Point, NC.

Interactions with ASDE-3. As calculated in the previous subsection, interference to ASDE-3 is possible when the ground transmitter (MRAALS, in this case) is within 18 nmi of an ASDE-3 radar, assuming minimum frequency separation and maximum antenna coupling. Of the potential ASDE-3 locations, only Honolulu International Airport is within 18 nmi of an MRAALS location (Kaneohe Bay MCAS). However, terrain obstructions will introduce additional propagation loss between these two locations, and no interference will occur. Interference to MRAALS receivers will not occur because of receiver processing.

Army Tactical Landing System (TLS)

TLS is identical in signal format to the AACS and MRAALS for azimuth and elevation signals, but also utilizes distance-measuring equipment (DME) in the 15.4-15.7 GHz band. However, TLS development has been terminated as a result of an in-process review held in June 1976, and will not become an operational system.[9]

[8]TELCON between J. Preis, ECAC, and J. Wily, NAVELEX, Arlington, VA, 17 May 1976.

[9]TELCON between J. Preis, ECAC, and J. Basarab, Army Electronics Command, Ft. Monmouth, NJ, 25 June 1976.

TALAR IV C Landing System

Two versions of the TALAR Microwave Instrument Landing System were developed by Singer-Kearfott: TALAR IV, which is the AN/TRN-27 and AN/ARN-97 in military nomenclature, and TALAR IV C, which is used only at civilian airports.

TALAR IV C equipments are presently installed at Aspen, CO; Steamboat Springs, CO; and Culver City, CA; an installation is planned for State College, PA. Technical characteristics of TALAR IV C are listed in TABLE 10.

Two interactions of TALAR IV C with ASDE-3 are possible: TALAR IV C ground transmitter interference to ASDE-3, and ASDE-3 transmitter interference to TALAR IV C airborne receivers.

Interference to ASDE-3. As in the case of AACS-to-ASDE-3 interference, propagation loss required to assure compatibility may be calculated from Equation 5. TALAR IV C mainbeam-to-mainbeam gain coupling is 66 dB (23 + 46 - 3 = 66 dB), allowing for a 3-dB polarization loss. The TALAR IV C transmitter spectrum is available in an FAA report.[10] At the minimum frequency separation between systems of 220 MHz (15760 MHz ASDE-3 frequency and 15540 MHz TALAR IV C frequency), the interference power primarily will be caused by the noise floor of the TALAR IV C transmitter, which is estimated to be 80 dB below the maximum transmitter output power. Assuming that the ASDE-3 receiver IF filter will reject

[10]R. A. Frazier, *In-Band Compatibility Analysis of the RTCA-Proposed Microwave Landing Guidance System (LGS) and Candidate Interim Systems*, FAA-RD-72-62, ECAC, Annapolis, MD, July 1972.

TABLE 10

TALAR IV C TECHNICAL CHARACTERISTICS

TRANSMITTER	
Operating Frequencies (GHz)	15.45, 15.46, 15.47, 15.48, 15.49, 15.50, 15.51, 15.52, 15.53, 15.54, (Selectable)
Peak Output Power (W)	16
Duty Cycle	0.5
Antenna Gain (dBi)	23
Antenna Polarization	Vertical
Elevation Antenna Coverage (degrees)	0 to 6
Azimuth Antenna Coverage (degrees)	±30
RECEIVER	
Frequency	Selectable, same as transmitter at desired landing area
IF Bandwidth (MHz)	3.5
Noise Figure (dB)	15
Antenna Polarization	Vertical
Antenna Gain (dBi)	8

the TALAR fundamental emission by considerably more than 80 dB (e.g., by use of a 7-pole IF filter), FDR will be approximately 80 dB. From Equation 5:

$$
\begin{aligned}
L_p &= 43 + 66 - 80 - (-88) \\
&= 117 \text{ dB.}
\end{aligned}
$$

This propagation loss will be exceeded at distances greater than 0.6 nmi, indicating that TALAR IV C interference to ASDE-3 should not be a problem unless both systems are sited at the same airfield. As of this time, no TALAR IV C equipments are planned for or installed at any proposed ASDE-3 location.

Interference from ASDE-3. In this case, mainbeam-to-mainbeam gain coupling is 51 dB (46 + 8 - 3 = 51 dB), and FDR of the aircraft receiver to ASDE-3 emissions was calculated to be 61 dB at the minimum frequency separation. The noise level of the receiver was calculated to be -93 dBm, considering the IF bandwidth of 3.5 MHz and noise figure of 15 dB. From Equation 5, required propagation loss is:

$$
\begin{aligned}
L_p &= 78 + 51 - 61 - (-93) \\
&= 161 \text{ dB.}
\end{aligned}
$$

Because of terrain shielding, this propagation loss will be exceeded between any proposed ASDE-3 location and aircraft landing at Aspen, Steamboat Springs, and State College. Aircraft landing at Culver City, however, will be within line-of-sight of the ASDE-3 proposed for Los Angeles International Airport (LAX) which is 2.2 nmi south of the Culver City airfield. Since the operating frequency

of the TALAR IV C transmitter at Culver City is 15500 MHz, FDR will be 63 dB when the ASDE-3 is tuned to 15760 MHz, and the required L_p is:

$$
\begin{aligned}
L_p &= 78 + 51 - 63 - (-93) \\
&= 159 \text{ dB.}
\end{aligned}
$$

This propagation loss will be exceeded when the distance between the ASDE-3 and the aircraft is more than 72 nmi. If the ASDE-3 is tuned to 16200 MHz, the distance separation required is 10 nmi; if the ASDE-3 is tuned to 17500 MHz, the distance separation required is 1.3 nmi. The interfering ASDE-3 signal will illuminate the aircraft twice per second (120/min), and will exceed the noise level of the aircraft receiver when the aircraft is also receiving valid TALAR IV C signals.

The effect of ASDE-3 signals on the TALAR IV C receiver output was analyzed by considering the receiver processing techniques. With the exception of the receiver front end and IF (which provide rejection of the fundamental frequency ASDE-3 transmissions), TALAR IV C receiver processing is identical to that used in the AN/ARN-97 receiver.[11] The desired signal PRF is 191.2, 192.8, 206.2, 207.8 kHz, transmitted in sequence. Both the desired PRF and the undesired PRF (18-20 kHz) will be detected and passed to the receiver processor (see Figure 5). The processor separates the desired localizer and glide slope signals by mixing and using low-pass filters. The low-pass filters will reject any ASDE-3

[11] *Technical Manual, Radio Receiving Set AN/ARN-97*, T.O. 12R5-2ARN97-2, Department of the Air Force, 23 September 1970, changed 25 July 1975.

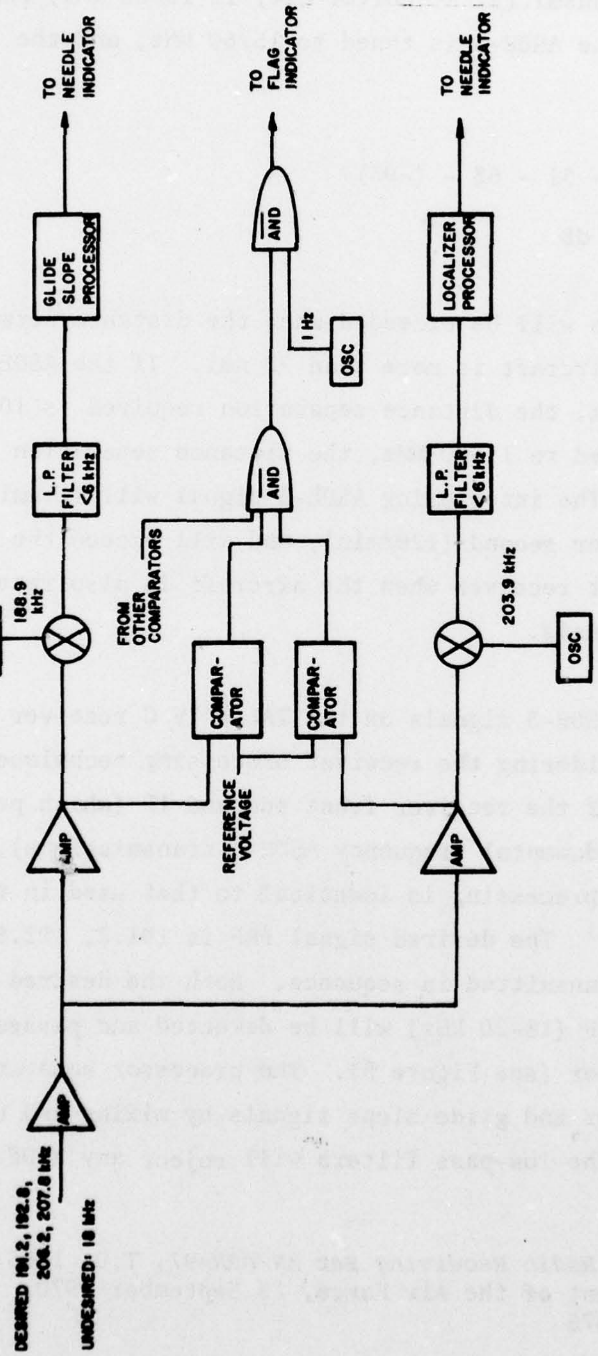


Figure 5. TALAR IV C receiver processor.

signals, and prevent the interference from affecting the needle indicator. However, the receiver processor also contains "noise monitor" circuitry, which compares input signals, power supply signals, and oscillator outputs to predetermined reference levels and produces outputs if any variance is detected. If any comparator produces an output, the flag within the pilot's readout will appear once per second during the period of comparator operation. Since the ASDE-3 interference will occur twice per second, and is likely to cause a comparator output, continuous flag oscillation is likely to occur when the aircraft is within the required distance separation calculated above, and will thus reduce the pilot's confidence in the needle indications.

Information[12] received from Hughes Aircraft Co., which operates the TALAR IV C equipment at Culver City, indicates that the five Hughes corporate aircraft are equipped with TALAR IV C receivers; system usage averages approximately one landing per day. There are no plans at the present time to discontinue use of this system.

Since calculations using synthesized transmitter emission spectrums show that the noise level is marginally exceeded at maximum frequency separation, frequency assignment is not necessarily a solution to this predicted interference problem. Further calculations should be made when the characteristics of the selected ASDE-3 design are known, and when a measured emission spectrum is available. The interference power is due to the skirts

[12]TELCON between J. Preis, ECAC, and Mr. Jessup, Hughes Aircraft Co., Culver City, CA, 9 June 1976.

of the emission spectrum, and may be controlled if required by transmitter waveguide filtering or pulse shaping. In any case, ASDE-3 frequency assignment in the upper portion of the 15.7-17.7 GHz band will most likely be required at LAX.

Military TALAR Landing System

The military version of the TALAR landing system, originally known as TALAR IV, consists of an AN/TRN-27 ground transmitter and AN/ARN-97 airborne receivers. It differs from TALAR IV C in that the military transmitter uses a fixed-frequency (15.5 GHz) magnetron with a peak power output of 25 watts, and the airborne receiver uses a tunnel-diode amplifier as the front-end and video detector. Antenna characteristics and receiver processing are the same as TALAR IV C.

The records of the Interdepartmental Radio Advisory Committee (IRAC) show that AN/TRN-27 equipments are authorized to operate at the following locations:

Ft. Campbell, KY	Camp Mackall, NC
Ft. Hood, TX	Ft. Stewart, GA
Dyess AFB, TX	Camp Robinson, AR
Ft. Bragg, NC	Camp Chaffee, AR
Ft. McClellan, AL	Blackstone, VA
Langley AFB, VA	Seymore-Johnson AFB, NC
Pope AFB, NC	Edwards AFB, CA
Goodfellow AFB, TX	Wright Patterson AFB, OH
Cape Canaveral, FL	

With the exception of Edwards AFB and Cape Canaveral, the above locations are used by the USAF Military Airlift Command (MAC) as landing areas for C-130 aircraft which are equipped with AN/ARN-97

receivers. System usage by MAC is for training and Joint Air Force/Army exercises; other locations are frequently used during exercises, with frequency clearance being obtained for the duration of the exercise only. MAC presently has no plans to discontinue use of this system.[13] The system at Edwards AFB is used in conjunction with drone approach and landing tests; at Cape Canaveral, the system is used as a landing aid in conjunction with the COMPASS COPE project, which is a remotely-piloted vehicle now under development.

Interference to ASDE-3. Interference considerations are the same as in the case of TALAR IV C, except that the AN/TRN-27 peak power is approximately 2 dB higher than the TALAR IV C transmitter. Propagation loss required to reduce interference power to the ASDE-3 receiver noise level is thus 2 dB more than in the previous calculation, or 119 dB. This propagation loss will be exceeded at distances greater than 0.9 nmi. No AN/TRN-27 equipments are within this distance of any proposed ASDE-3 location, and thus, no interference is expected to occur.

Interference from ASDE-3. The AN/ARN-97 airborne receiver bandwidth is determined by the tunnel-diode amplifier used as the receiver front end and video detector. The bandwidth is not defined in the applicable technical manual (Reference 11), but information received from the manufacturer indicates that the 3-dB bandwidth is greater than 200 MHz, and that the 20-dB bandwidth is approximately 2.2 GHz. This receiver is thus considerably less selective than the TALAR IV C receiver, and is more susceptible to adjacent-signal interference.

[13] TELCON between J. Preis, ECAC, and Mr. Brandstatter, MAC Communications, Scott AFB, IL, 14 June 1976.

The propagation loss required to reduce the ASDE-3 interference to the AN/ARN-97 noise level may be calculated from Equation 1. Mainbeam-to-mainbeam coupling is (46 + 8 - 3 = 51 dB), and FDR at the minimum frequency separation between systems (15760 - 15500 = 260 MHz) was calculated to be 9 dB. The receiver noise level is approximately -98 dBm. Thus,

$$L_p = 78 + 51 - 9 - (-98)$$

$$= 218 \text{ dB.}$$

The distance at which free-space propagation loss will exceed 218 dB is beyond line-of-sight, indicating that an aircraft using the AN/ARN-97 receiver may be affected whenever it is within line-of-sight of an ASDE-3 radar. The AN/ARN-97 may be used up to 28 nmi from the landing area, and the elevation angle from the ground may be up to 6 degrees; thus, the aircraft may be utilizing the system up to 18,000 feet in altitude. Typically, however, acquisition of the landing system information occurs between 3000 and 1500 feet in altitude, and at 5 to 10 nmi from the landing area. Calculations of propagation loss between several proposed ASDE-3 locations and military TALAR locations were made, using the maximum ASDE-3 antenna elevation of 300 feet and a 3000-ft TALAR-equipped aircraft altitude. TABLE 11 shows the results of these calculations, which utilized the ECAC terrain files and considered the closest proposed ASDE-3 sites to the AN/TRN-27 locations.

As shown in TABLE 11, the value of a 218-dB propagation loss is exceeded in all but two cases, one of which is a marginal case of tropospheric scatter loss between LAX and Edwards AFB. The path between Atlanta and aircraft landing at Fort McClellan is

TABLE 11

PROPAGATION PATH INFORMATION - ASDE-3 TO MILITARY TALAR RECEIVERS

ASDE-3 Location	AN/TRN-27 Location	Distance (nmi)	Propagation Loss[a] (dB)
Washington (DCA)	Langley AFB, VA	111	241
"	Blackstone, VA	115	239
Atlanta (ATL)	Ft. McClellan, AL	73	159
Tampa (TPA)	Cape Canaveral, FL	108	236
Miami (MIA)	"	162	260
Memphis (MEM)	Ft. Campbell, KY	156	260
"	Camp Robinson, AR	115	224
Dallas (DFW)	Dyess AFB, TX	145	256
Houston (IAH)	Ft. Hood, TX	134	249
Las Vegas (LAS)	Edwards AFB, CA	151	266
Los Angeles (LAX)	"	64	213

[a]Loss at 15700 MHz. ASDE-3 antenna height is 300 feet and AN/ARN-97 height is 3000 feet.

line-of-sight, and is likely to cause flag oscillation on the pilot's readout device (see the TALAR IV C analysis for effects on receiver processing). Likewise, if landing patterns used during military exercises are within line-of-sight of a proposed ASDE-3 location, interference is likely to occur.

Since this interference problem results from the relatively poor receiver selectivity of the military equipment, modifications of ASDE-3 will not provide a solution. Even if ASDE-3 were operated at the upper end of the 15.7-17.7 GHz band, interference would be likely to occur. Operational coordination between systems will be required to prevent interference.

SECTION 3
RESULTS AND RECOMMENDATIONS

RESULTS

Ground-Based Environment Analysis

1. At Honolulu, Miami, and Las Vegas, frequency-use coordination with environmental equipments will be required, and only portions of the 15.7-17.7 GHz range will be available for use by ASDE-3:

Honolulu	17.02-17.7 GHz
Miami	15.7-16.0 GHz
Las Vegas	15.92-16.2 GHz.

2. At Portland, the calculated required frequency separation between a nearby AN/MPQ-4 radar and the ASDE-3 will exceed that available. Time-sharing coordination is likely to be required.

3. At the remaining 29 sites, the entire 15.7 to 17.7 GHz band can be used by the ASDE-3 radar.

Airborne Equipment Analysis

Operation of ASDE-3 radars in the co-equal band (15.7-16.2 GHz) will be compatible with the use of airborne terrain-following radars and airborne beacon transponder; however, it may be incompatible with airborne attack/bomb/fire-control radars as follows:

1. Interference to the ASDE-3 by attack/bomb/fire-control radar is possible when the ASDE-3 is tuned to the upper end of the 15.7-16.2 GHz band or when attack/bomb/fire-control radars operate at the low end of the 16-17 GHz band. This is a manageable problem since interference may be avoided by frequency-use coordination in the vicinity of military aircraft training areas.

2. Interference to attack/bomb/fire-control radars by ASDE-3 is possible regardless of ASDE-3 tuning within the 15.7-16.2 GHz band, when the radar-equipped aircraft is within line-of-sight of the ASDE-3. Further investigation of radar receiver processing and military aircraft training areas is required to determine degree of performance degradation that may be experienced.

Aircraft Landing Systems Analysis

1. Several aircraft landing systems either operate in or are proposed to operate in the 15.4-15.7 GHz band: Microwave Landing System (MLS), Aircraft Approach Control System (AACS), Marine Remote Area Approach and Landing System (MRAALS), Tactical Landing System (TLS), TALAR IV C, and TALAR.

2. No interference will occur between an ASDE-3 and any of the following systems: MLS, AACS, MRAALS, and TLS.

3. Interference to TALAR IV C aircraft receivers is possible in the vicinity of Los Angeles International Airport, regardless of ASDE-3 tuning within the 15.7-17.7 GHz band. Time sharing is likely to be required to prevent interference.

4. Interference to TALAR aircraft receivers at Ft. McClellan, AL, is possible due to emissions of an ASDE-3 located at Atlanta

International Airport, regardless of ASDE-3 tuning within the 15.7-17.7 GHz band. The interference will result primarily from the broad selectivity of TALAR aircraft receivers. Time sharing is likely to be required to prevent interference.

General

The EMC problems identified in this report are applicable regardless of whether the ASDE-3 operates in the single-frequency or frequency-agile mode.

RECOMMENDATIONS

Military attack/bomb/fire-control radar receiver analysis should be performed to determine the degree of degradation that may be expected from ASDE-3 emissions.